OPTIMAL ALLOCATION OF AGRICULTURE WATER FOR IRRIGATION OF MULTIPLE CROPS USING NONLINEAR PROGRAMMING

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ABSTRACT

Finding the optimum cultivation pattern in agricultural development projects for maximizing the net economic profit under adequate and limited water supply, area of the farms conditions is complicated and requires the use of optimization methods. This study gives the optimal distribution of crop areas, irrigation water needs of crops and total profit for the farm under adequate and limited water supplies. A non-linear optimization model is proposed for optimal cropping patterns under water deficits. The objective function of non-linear model is to maximize total net benefit return from all crops in the Qazvin plain. The model is solved using Lingo solver package for conditions existing in region. The results showed that optimizing the cropping patterns along with proper the allocation of irrigation water has substantial potential to increase the net return of agricultural water.Also an optimal cropping pattern cultivation pattern considering maximum net economic profit was found from scenario 40% water deficit.

Keywords: Cropping pattern; deficit irrigation; net profit;optimization;nonlinear programming.
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1 INTRODUCTION

Water is one of the important natural resources that has strongly used by multiple sectors. It is one of the main production inputs in agriculture and has a specific role in maintainable development of agriculture(Dinar et al., 1997). Recently, the management and planning of water resources have become an important topic in most countries. Cropping pattern is one of the most effective parameters in water productivity. The cropping pattern for each district is expanded on the basis of local and temporal considerations with due attention to major policies of the agriculture sector and then used as the basis for planning the increasing of water productivity(Keramatzadeh et al., 2011). Over the former two decades, various methodologies as well as simulation and optimization models have been expanded for scheming and managing water resources.

A number of these models concentrate on water repartition optimization while others focus on economic optimization (Gustavo et al., 1997).The models that are used in the optimization can be linear or non-linear. Although linear programming is a technique for the optimization of a linear objective function, subject to linear equality and linear inequality constraints, conditions that are not always gratified. Nonlinear optimization models do not have the linearity limitation(Hillier and Lieberman, 1980).Kodal(1996)offered optimal cropping pattern by using a linear model.Mainuddin et al., (1997) developed a linear model for obtaining optimal cropping pattern using LINDO.Carvallo et al., (1998)developed a non-linear optimization problem for the determination of optimal cropping patterns. They used GAMS-MINOS software package to solve the problem. Kuo et al., (2000)suggested a genetic algorithm optimization model for the optimal cropping pattern in an irrigation plan. SabuandSudhindra (2000)suggested a model based on both stochastic dynamic programming and deterministic dynamic programming for the optimal cropping pattern in a canal command area. Kumar et al., (1998)have used a linear model to resolve the optimal cropping pattern. BenliandKodal (2003)developed a non-linear optimization model for water distribution at the farm level with inadequate water resources in the southeast of the agricultural site in Anatolia, Turkey. The problem was also solved by a linear programming (LP) model, in order to show the difference between non-linear programming (NLP) and linear programming models. After the examination of NLP and LP model solutions, it shows that, the NLP model can give higher farm income values than the LP model under deficit irrigation conditions.Kipkorir et al., (2002),GhahramananandSepaskhah (2004), and Li et al., (2005)used both linear and non-linear optimization methods in their studies of optimal cropping pattern to make the most of net profit from farms.

The purpose of this paper is to determine the optimal crop pattern under deficit irrigation conditions with regards to regional limitations and water availability using nonlinear programming. In order to solve the model, standard software named Lingo has been used.

2 MATERIAL AND METHODS

Qazvin plain, shown in figure 1, is located in the northwest of Iran where agriculture is the primary economic activity.Mean annual precipitation, temperature, and evaporation in the region are 269 mm, 11.6 ºC, and 1063 mm, respectivelyThe Qazvin Irrigation Network contains zone of 60,000 hectares and its water is provided from Taleghan Dam and 102 integrated wells that spread along the network areaThe prevalent cropping pattern in the region often include: wheat (71%), barley (11%), corn (2%), tomato (4%) and alfalfa (12%). Table 1 shows the characteristics of major crops, including the cultivated area (A_i), maximum yield (Y_m), yield response factor (K_y), annual water requirement (W_i) and production cost (P_c) (Ministry of Jihad–e–Agriculture of Iran, 2012).

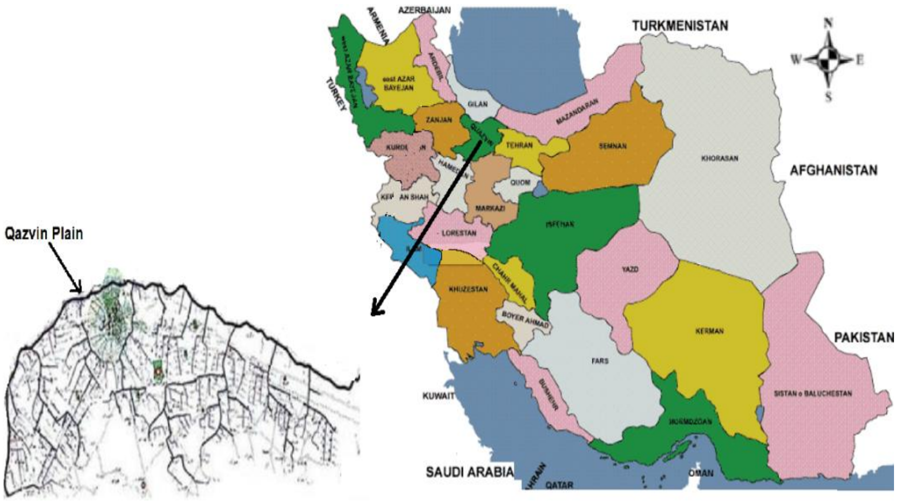

Figure 1. Location of irrigation network in province of Qazvin, Iran

Table 1.Cultivated area (A_i), maximum yield (Y_m), yield response factor (K_y), annual water requirement (W_i) and production cost (P_c)

crop	wheat	barley	corn	tomato	alfalfa
A_i (ha)	26927	4272	906	1446	4502
Y_m (Kg/ha)	4052	3923	64853	56611	12380
K_y*	1.2	1.1	1.35	1.09	1.1
P_c (Rls/ha)**	6965090	6149230	8281020	9715350	8854900
W_i(m^3/ha)	5069	5103	13245	31051	17086

*Najarchi et al.,(2011)
**33000 Rls=1 US dollar.

The main objective of the methodology was to find optimum crop pattern, optimal volume of water saved and maximum farm benefit.

2.1 Water yeld function

Non-linear functions of crop production have been generated from behavior actual yield of crops against various quantities of irrigation water using excel software. The results shown in table 2.

Table 2. The crop water-yield functions of the cultivated products in the region

Crop	Water-yield Function
Wheat	$Y= -0.0125w^2 + 125.89w - 312144$ $R^2 = 0.846$
Barley	$Y = 0.0018w^2- 10.801w + 19578$ $R^2 = 0.996$
Corn	$Y = -0.0018w^2 + 46.689w - 238149$ $R^2 = 0.994$
Tomato	$Y = -0.0003w^2 + 13.26w - 81223$ $R^2 = 0.986$
Alfalfa	$Y = -8E-05w^2+ 2.6445w - 9741$ $R^2 = 0.942$

2.2 Objective function

For the purposes of this paper, the objective function is the maximum net benefit. The net profit achievable is represented by the following function:

$$Maximize \sum_{i=1}^{5} Y_i A_i P_i - \sum_{i=1}^{5} A_i P_i \quad (1)$$

Where i is the crop number; Y_i is the yield of crop i as a function of gross applied water depth (Kg /ha); A_i is the area of crop i (ha); Pi is the price of crop i (Rls /ton) and Pi is the crop production cost of crop i (Rls/ha).The term Y_i 'production function' describes the relationship between the yield of a crop to different irrigation levels. To use a net benefit economic maximization technique for a water production function, the knowledge of the relationship between yield and some measure of water used by the plant is required(Table 2). Ghahraman and Sepaskhah (1997) have presented a simple optimization model, for water production functions according to the function proposed by Doorenbosand Kassam(1979).The relationship between yield and water shown by the following function:

$$1 - \frac{Y_a}{Y_p} = K_Y \left[1 - \frac{W_a}{W_p} \right] \quad (2)$$

WhereY_a and $Y_p$are actual and potential crop yields (kg/ha), W_a and W_m are actual and potential water demand (mm), respectively and K_y are the yield response factors (dimensionless), Y_p and $K_y$are given in table 1.

Subject to:
Water Supply constraint:

$$\sum_{i=1}^{5} W_i A_i \leq Q \quad (3)$$

W_i is the gross water depth to crop i per unit area (m^3/ha) and Q=298 is the amount of available water for irrigation, million m^3 (MCM).
Constraints for total allowable area:

$$\sum_{i=1}^{5} A_i \leq A_T \quad (4)$$

A_T=60000 is the total available land for cropping (ha).

Non-negativity constraint:
$A_i \geq 0$. (5)

The cost information such as production costs is presented in table 1.

3 RESULTS AND DISCUSSION

The non-linear program was assembled to determine the optimal cropping pattern and farm income forfull irrigation and deficit irrigation, using the crop water-yield functions.The results obtained by the model are given in table 3.

Table 3.Optimum crop pattern, volume of allocated water and net benefit under full and deficit irrigation water conditions.

Crop		Presentconditions	Deficit irrigation ratio (%)					
			100 (298MCM)	90 (268MCM)	80 (238MCM)	70 (208MCM)	60 (178MCM)	50 (149MCM)
Area (ha)	Wheat	26927	27000	24600	21867	19133	18223	18223
	Barley	4272	4475	4028	3580	3132	2685	2237
	Corn	906	906	906	906	906	906	906
	Tomato	1446	1590	1507	1339	1172	1004	837
	Alfalfa	4502	4888	4127	3586	3045	1942	558
Total area(ha)		38053	38859	35168	31278	27388	24760	22761
Net benefit(Billion Rls)		880	973	888	794	699	633	580
Benefit changes (%)		0	+11	+1	-10	-19	-28	-34

According to table 3, six irrigation water alternatives (100, 90, 80, 70, 60 and 50%of full irrigated volume) wereinvestigated. The optimal cropping pattern for the sufficient water capacity situations (100%) suggest rising the cultivated area of barley, tomato and alfalfa from 4272, 1446, and 4502 of the existent condition to 4475, 1590 and 4888 hectares respectively. Also by reducing the amount of irrigation water, the cultivated area and net benefit obtained from the products are reduced, but the volume of saved water is increased. For example, the net profit shows an increase of 11 and 1 percent based on 100% and 90% of water supply capacity and also in 20%, 30%, 40% and 50% in situation of water deficit the net profit shows a decrease of 10, 19, 28 and 34 percent. Fig.2 shows the net benefit changeunder full and deficit irrigation water compared with the exciting situation.

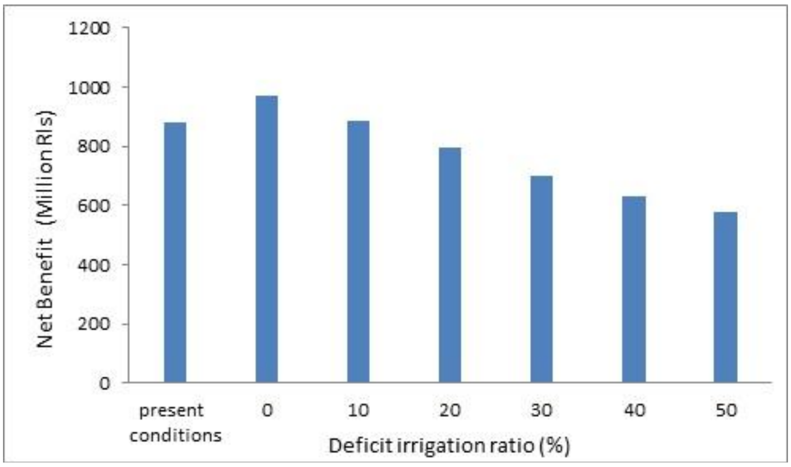

Figure 2.The net benefit changes under full and deficit irrigation water conditions

4 CONCLUSIONS

In this paper, a nonlinear model based on optimization of cropping patterns is developed under water deficit.The optimization results shows that the farmers can choose the most profitable crops, area size and the irrigation level for selected cropsin particular, the optimization model helps growers advantage the most from the initial state by considering the relationship between a crop yields. Knowledge of water-yield relation (production function) is necessary in order to reach optimal amounts of irrigation water and supreme production. Optimizing water use is a type of management alternatives that may set up relationship between land and water under inadequacy of water/ land situations.In the present study, nonlinear programming model developed for the maximum production in deficit irrigation conditions.The overall results indicated that:

1. When supplies are limited by droughts or other factors, deficit irrigation can be used as a tactical measure to reduce irrigation water use.
2. By reducing the amount of water given to the land under deficit irrigation situations, the cultivated area and net income achieved from the products is reduced but the volume of saved water is increased.
3. The complete results indicated that nonlinear programming can be used to determine crop patterns by varying the parameters such as deficit irrigation.
4. Optimal cultivation pattern considering maximum net economic profit was obtained from scenario 40% water deficit.

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